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THE SLAGGING TYPE OF GAS PRODUCER

WITH A BRIEF REPORT OF PRELIMINARY TESTS

BY

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THE SLAGGING TYPE OF GAS PRODUCER, WITH A BRIEF REPORT OF PRELIMINARY TESTS.

By Carl D. Smith.

INTRODUCTION.

The gas producer is to-day receiving wide attention from mechanical and chemical engineers, and general interest is shown in any experiments to determine its utility in power plants as a means of reducing the cost of fuel. In view of the importance of the problem the Bureau of Mines is conducting a series of investigations to determine the value of the slagging type of producer in the utilization of high-ash fuels and the conditions under which this type is most satisfactory. Tests have been made with coke, with limestone as a flux, for intermittent and for continuous runs up to 100 hours, and the results obtained give promise that high-ash fuels may be successfully utilized in this type of producer.

EXTENT OF THE USE OF THE GAS PRODUCER.

The application of the gas producer for power purposes has made notable progress during the past decade, and its use for metallurgical work also has been greatly extended, although in this field it has been used for a much longer period. Ten years ago there were very few producer-gas power plants in the United States compared with the number now installed. At present producer-gas power is being utilized for a great variety of purposes, and in a majority of the plants with entire satisfaction.

GAS PRODUCERS USING ANTHRACITE.

The success and reliability of producers designed for and operating with good grades of anthracite pea or nut coal are pretty well established, but although there are many plants operating with different grades of bituminous coal with excellent results, it can not be said that the development of the bituminous-coal producer has reached the same degree of perfection as the anthracite producer.

GAS PRODUCERS USING BITUMINOUS COAL.

The use of bituminous coal in gas producers introduces complications with which the anthracite producer does not have to contend. Oftentimes, when coking coals are used, difficulty is experienced in keeping the fuel bed in a uniform condition. The tar-forming constituents from the volatile matter condense readily and with some fuels considerable tar is produced which, if not removed from the gas, clogs restricted passages and gives trouble by clogging engine valves and governors. In the operation of gas producers on bituminous coal there is little definite information concerning the proper thickness of the fuel bed and the best rates for combustion. It is not definitely known what amount of steam per pound of fuel should be used with different grades of bituminous coal under different operating conditions for the best results.

THE GAS PRODUCER FOR HIGH-ASH FUELS.

The adaptability of the gas producer for the utilization of low-grade or high-ash fuels was pointed out early in its history, but the development of producer apparatus for the consumption of such fuel has never made marked progress, and at the present time but little use is made of those fuels especially high in ash. There are two or three European plants reported to be operating satisfactorily upon fuels containing as high as 50 to 60 per cent of ash, but the use of fuels of this type is by no means general, although there is said to be much interest in the matter and also a full realization of the desirability of utilizing all low-grade fuels.

In the United States even less has been accomplished, and so far as is known there is no plant operating regularly on coal of very high ash content. Several tests on fuels containing from 30 to 44 per cent ash have been made by the Bureau of Mines, but in a producer adapted only for the best grades of coal.

The results obtained under these conditions in most cases would not be considered practical from a commercial standpoint, but they do indicate clearly the possibilities that may be realized with these fuels. In many sections of the United States there are large quantities of these low-grade fuels, a rational utilization of which would not only be of distinct advantage to the communities in which they are found, but also would result in a material saving of the Nation's fuel resources.

PURPOSE OF THE BUREAU OF MINES TESTS.

It is with the view of throwing some light on the problems connected with the utilization of fuel in gas producers, especially of those fuels which are high in ash, that producer-gas investigations are being made by the Bureau of Mines.

CONSTITUENTS OF PRODUCER GAS.

Producer gas consists necessarily of a mixture of several distinct gases, of which some are combustible, the rest noncombustible. In the generation of producer gas it is desirable to maintain as high a percentage of combustible gases as is consistent with efficient operation. The principal combustible in producer gas is carbon monoxide. This is a colorless, odorless gas, and is a product of incomplete combustion in which the carbon combines with one-half the oxygen that is required for complete combustion. The formation of this gas takes place when air passes through a thick fuel bed of incandescent coke or carbon and probably according to the formul

$$CO_2+C=2CO.$$

EFFECT OF HIGH TEMPERATURE IN GAS PRODUCER.

As a result of laboratory experiments on the rate of formation of carbon monoxide, it has been shown that, for the production of high percentages of carbon monoxide, the producer fuel bed should have a temperature of 2,300° F. or over, and that by operating at these temperatures the capacity of the producer would be greatly increased.[a] In usual practice, however, great care is taken to prevent such high temperatures in order to avoid fusing the ash and the consequent serious clinker difficulties. High temperatures are thus very desirable on the one hand, whereas on the other they are undesirable, and with coals having an easily fusible ash they may be a great disadvantage. In general, the result of these conflicting conditions on the operation of producer plants is a compromise in which the temperatures maintained are as high as the character of the ash permits without fusion and the formation of objectionable clinkers.

REASON FOR CHOOSING A BLAST-FURNACE PRODUCER.

In an effort to obtain the advantages, as well as to avoid the disadvantages resulting from high temperatures in producers of the usual type, tests with a producer of the blast-furnace type, or a slagging producer, were suggested early in the history of the bureau. In such a producer ash can be removed as a liquid slag, and it was believed that fuels containing a high percentage of ash could be thus utilized, and that the accompanying temperatures would be ample for the production of a high percentage of carbon monoxide. The slagging type of producer was therefore selected for the investigation discussed in this paper.

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[a] See Bulletin 7. Bureau of Mines, Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 58 pp.

THE SLAGGING TYPE OF GAS PRODUCER.

EARLY DEVELOPMENT.

The slagging or blast-furnace type of gas producer was among the first made. Bischof is usually credited with the first internally fired gas producer, built in 1839, and only a year later, in 1840, Ebelmen built the first slagging producer at the iron works of Audincourt in France. Charcoal was the fuel used. Iron-furnace slag and clay were charged into the producer with the fuel. This formed with the ash an easily fusible slag which ran off at the bottom of the hearth. For several years following there seems to have been no development in producers of this type. The "Transactions" of the American Institute of Mining Engineers for 1881 contain a brief description of a slagging producer built by W. J. Taylor and operated in Chester, N. J. Very satisfactory results were reported, as follows: Gas of excellent quality, uniformity of operation, uninterrupted service (four weeks' operation without any shutdown being cited), and ash easily removed as a liquid slag. Small sizes of anthracite were used for fuel, and 30 to 40 per cent of blast-furnace slag was added to flux the ash. There seems to be, however, no record of any results from subsequent operation, and information as to success or failure is not to be found. At any rate the producer seems to have dropped out of use, while the development of producers of other types continued.

A FRENCH GAS PRODUCER.

A more recent application of the blast-furnace type in producer design is found in the development of the "S. F. H." gas producer in France. This producer is reported to be operating satisfactorily and giving excellent results. Ash is removed from time to time as a liquid slag, the gas is of good quality, and low grades of fuel are said to be readily gasified.

In a description of this producer the following statements are made:[a]

> The slagging type of gas producer permits excellent utilization of the fuel. The composition of the gas is almost constant for a given fuel and its calorific power is extremely regular.
>
> The S. F. H. gas producer permits the utilization of all kinds of fuels, particularly wastes, refuse coal, breeze, coal cinders, etc., the only condition being that they have a content of fixed carbon sufficient to develop heat enough in gasification to distill the volatile matter, to vaporize the contained water, and to fuse the ash.

It is also stated that the amount of heat required to fuse the ash is exceedingly small and is much less than the heat value of the carbon lost in the ash from producers having grates. Reference is made to a "suitable flux for fusing the ash," but no statement is given as to what it is.

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[a] Sepulchre, M., Notes on the S. F. H. gas producer, cleaned by fusion of the cinders. Revue de metallurgie; mémoires, vol. 6, p. 730.

A battery of these producers, installed at the glassworks at Giron-court-on-Vosges, in 1907, furnishes gas for several large plate and annealing ovens and, as is reported, in a most satisfactory manner. An analysis of the fuel used is given as follows:

Analysis of fuel used in a French gas producer.

Constituent.[a]	Per cent.
Moisture	15
Volatile matter	25
Fixed carbon	35–40
Ash	20–25

[a] The sulphur, 6 to 7 per cent, chiefly in the form of iron pyrites, was determined separately.

An analysis of the gas is reported as follows:

Analysis of gas in a French gas producer.

Constituent.	Per cent.
CO_2 and SO_2 (determined together)	2–3
CO	28–30
H_2 and CH_4	9–10

Results like the above are at once seen to be very creditable, and show a satisfactory utilization of comparatively low-grade fuel. If it is found that the low-grade fuels of the United States can be utilized economically in a commercial way in producers of this type, and should the use of these producers become general where such fuel is available, a great saving in the better grades of coal would result.

PRELIMINARY TESTS.

EQUIPMENT.

The equipment installed for the investigation now in progress by the Bureau of Mines consists of the producer, a scrubber, gas meter, blower, preheater, steam boiler, and such scales, thermometers, thermocouples, and gas-sampling devices as are necessary.

THE PRODUCER.

The producer consists of a cylindrical steel shell lined with brick and provided with a slag notch, through which the liquid slag is tapped off. Near the base of the producer are six air tuyères, and, in addition to these, four separate tuyères are provided at points above the air tuyères, through which steam may be admitted. Fuel is charged at the top of the producer and the gas passes off through the side at a point near the top.

Because of the extremely high temperatures that prevail in the combustion zone, it has been necessary to provide a special cooling device in order to prevent the brick lining from melting and fluxing with the slag. For this purpose a water-cooling arrangement was devised consisting of a coiled pipe embedded in the brick lining. Between the coil and the fire is a 4½-inch layer of magnesite brick. This cooling coil extends over a space of about 20 inches just above the air tuyères. The air and steam tuyères are of cast iron and extend through the brick lining to the fire, but they are water cooled and thus protected from the intense heat. Steam, however, does not come in direct contact with any water-cooled surfaces and consequently there is little, if any, condensation in the steam tuyères. The top of producer also is water cooled.

THE SCRUBBER.

The scrubber consists of a cylindrical shell containing numerous water sprays, but no baffle plates nor layers of coke. Gas enters at the bottom of the scrubber through a water seal, passes upward through a dense spray or fog, and finally through a layer of excelsior, which acts as a dry scrubber. From the scrubber the gas passes directly to a large gas meter.

THE AIR BLAST.

The air blast for the producer is furnished from a blower of the positive-pressure type. The quantity of air used depends upon the rate of fuel consumption, and is controlled by a regulating valve through which a part of the blast may be by-passed to the atmosphere. The air-blast pressures in the tuyères also vary according to the rate of fuel consumption, from 5 or 6 inches of water to about 16 inches at the higher rates. Steam is supplied as desired at definite rates by a small gas-fired boiler. Preheating of the air blast is accomplished by passing the air through a heater in which a portion of the gas produced is used for fuel.

NATURE OF THE TESTS.

In order to establish a fundamental basis to which the results of subsequent tests may be referred, the first tests have been made with coke, a fuel nearly elementary in character, with which complications due to the volatile constituents of bituminous coal are avoided. Tests will be made, however, of different grades of bituminous coal as well as tests of high-ash coals. Although the investigation on the utilization of fuels in a slagging producer includes tests to determine the effect of different operating conditions, several preliminary tests have been made to determine the feasibility of melting the ash and removing it from the producer as a liquid slag. The general trend of the results of these tests is briefly given in the following pages.

RESULTS OF THE TESTS.

The readiness with which a fuel ash will melt and form a fluid slag depends upon the relative percentages of its constituents and the temperature to which it is subjected. Usually the desired fluidity is increased by the addition of a flux such as limestone.

In the preliminary trials with the slagging producer the coke used contained about 11 per cent of ash, and in order to make a more liquid slag limestone crushed to about half-inch size was added to the coke charge.

Analyses of both the ash and the limestone are given in the following table:

Analyses of coke ash and limestone.

Constituents.	Ash.	Limestone.
Silica (SiO_2)	54.83	1.73
Alumina (Al_2O_3)	31.94	.93
Ferric oxide (Fe_2O_3)	7.22	.80
Calcium oxide (CaO)	2.06	52.20
Magnesium oxide (MgO)	.25	1.48
Potassium oxide (K_2O)	1.49	.00
Sodium oxide (Na_2O)	1.04	.00
Loss on ignition	1.19	43.28
Total	100.02	100.42

[a] Analysis of ash by F. M. Stanton; analysis of limestone by A. C. Fieldner.

Although computations were made from these analyses for the amount of limestone required to produce the more readily fusible slags, the results from the use of the calculated amounts were unsatisfactory. When the producer is in operation large quantities of fine coke ash blow over with the gas because of the heavy air blast, and it is probably true that some of the limestone is blown over in the same manner. At least on one occasion practically all of the coke ash and limestone escaped in this way. Under these conditions computations from the analyses were of little use in determining the necessary limestone. The problem has been one of trial rather than calculation, and tests have been made with different amounts of limestone, varying from 4 to 28 pounds per 100 pounds of coke charged.

Use has also been made of a triangular slag diagram which is the result of work on slags and slag-fusion temperatures by Boudouard. From this diagram the approximate fusion temperatures may be found for different percentages of the three principal constituents of slag. There seems to be some question, however, as to whether a slag in which the proportions of these constituents are such as to give a low-fusion temperature is, at the same time, one which will be least viscous or most fluid as the temperature increases.

In the first trial made, about 30 pounds of coke was burned per square foot of fuel-bed area per hour, and to each 100 pounds of coke charged, 6 pounds of limestone was added; the fuel bed was maintained at a depth of 6 feet; no steam was used, nor was the air preheated. The ash and limestone fused into a pasty mass at the bottom of the producer, and when the slag notch was opened the semifluid slag flowed out very slowly; it was exceedingly sticky, solidified quickly and presented when cold a black, glassy appearance. Throughout the day of the first trial the slag continued to have the same general characteristics, being black and sticky, but it did not, apparently, accumulate or solidify in the producer. Toward the latter part of the day a sample of gas was taken as a matter of interest; this sample, when analyzed, showed 31 per cent CO and less than 2 per cent CO_2.

From the slag diagram of Boudouard the amount of limestone required to make up a slag having a low-fusion temperature was only 4 pounds per 100 pounds of coke. A test was made with these proportions but the results from a slagging standpoint were unsatisfactory. The slag was very sticky and would hardly flow from the producer. During this trial no steam was used and the air blast was at room temperature. After a few hours' run the slag began to solidify within the producer, the test was stopped and the fuel bed immediately dumped. The bed was dumped easily, but in the bottom of the producer there was an accumulation of clinker 6 to 8 inches deep which was very sticky, and the removal of this required considerable effort. The quality of the gas was satisfactory, being high in CO and very low in CO_2.

Trial runs with 12, 20, and 28 pounds of limestone were made under the same conditions of operation, namely, no steam, air blast at room temperature, and fuel bed at a depth of 6 feet. With 12 pounds of limestone per 100 pounds of coke fair results were obtained; the slag was still a little sticky and black, but it ran freely from the producer and there were no evidences of clinkering or of slag accumulation. With 28 pounds of limestone the maximum amount that would form a fluid slag was undoubtedly passed. In this case the slag presented little fluidity and completely solidified soon after leaving the producer. At the close of the trial a mass of clinker 4 to 5 inches thick was found on the producer bottom; it was very brittle, however, and was easily broken to pieces and removed. In a trial with 20 pounds of limestone per 100 pounds of coke satisfactory results were obtained, the slag being much less viscous than on any preceding trial; it ran from the producer very freely and remained sufficiently liquid to spread over a considerable area before

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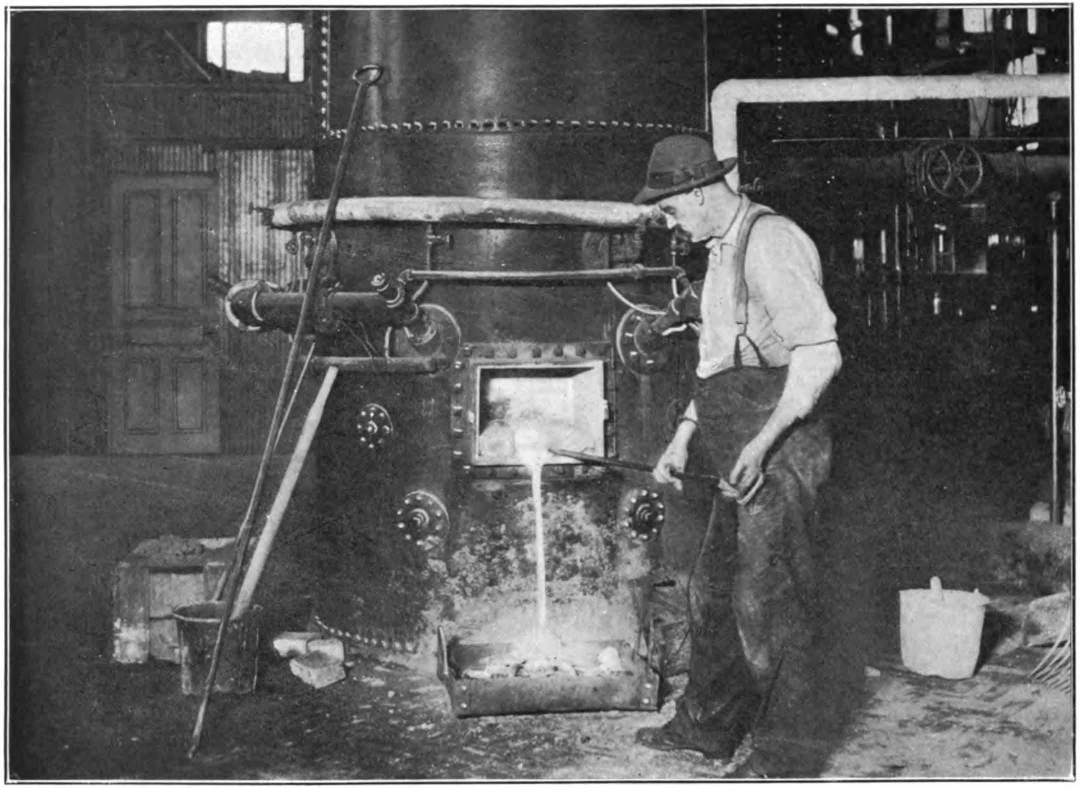

TAPPING OFF THE SLAG.

solidifying. The accompanying plate (Pl. I) gives a view of a satisfactory slag while it ran from the producer.

INTERMITTENT RUNS.

In attempting to operate the producer intermittently—that is, with the fire banked at night—considerable difficulty was experienced from the accumulation of clinker during the shutdown, more especially when a cold-air blast was used. After shutdowns of one night the producer has been started a number of times on cold air with satisfactory results, but with more than one shutdown there were excessive clinker accumulations. With preheated-air blast, however, a 4-day intermittent run was made possible. Some clinker accumulated, but gas of good quality was produced throughout the entire operating time. A producer of the blast-furnace type can hardly be expected to operate intermittently because of its inherent tendency to "freeze" during shutdowns.

CONTINUOUS RUNS.

Continuous runs of from 75 to 100 hours have given very satisfactory results, both as regards the character of the slag and the quality of the gas. In one test of 76 hours' duration the gas produced was uniform in heat value and of very good quality, averaging for the run about 31 per cent CO and less than 1½ per cent CO_2. Some of the time the slag was a little sticky and did not flow very freely, but it was tapped off regularly once an hour throughout the test, and at no time did it cause any serious difficulty. About 20 pounds of coke was consumed per square foot of fuel-bed area per hour, and to each 100 pounds of coke 15 pounds of limestone was charged. The air blast was preheated to about 440° F.; no steam was used. At the end of the test there was a layer of hard, flintlike clinker 4 to 6 inches thick in the bottom of the producer.

A run with 15 pounds of limestone per 100 pounds of coke lasted more than 100 hours and gave satisfactory results. The air blast was preheated and steam was used. The slag flowed readily throughout the run, and at the close of the test the producer was found to be comparatively clean and clear from clinker.

Other runs of 100 hours' duration have been made, with and without preheated-air blast, with and without steam, and in each case little difficulty was experienced in tapping off the slag.

With preheated-air blast a more fluid slag is generally obtained, and the indications are that higher rates of combustion can be maintained.

The use of steam in addition to the air blast appears to have no appreciable effect upon the slagging of the ash, and in several tests 0.75 pound of steam per pound of fuel consumed has been used. That the steam produces no cooling effect upon the slag is undoubtedly due to its delivery to the producer through separate tuyères at points considerably above the air tuyères.

CONCLUSION.

The readiness with which the ash has been made to slag in the tests with the producer used gives much encouragement for the use of the slagging producer and strengthens the belief that high-ash coals may be successfully utilized in producers of this type.

PUBLICATIONS ON FUEL TESTING.

The following publications can be obtained free of cost by applying to the Director of the Bureau of Mines, Washington, D. C.:

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp.

BULLETIN 5. Washing and coking tests of coal at the fuel-testing plant, Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delameter, J. W. Groves, and K. M. Way. 1910. 62 pp.

BULLETIN 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker. 1911. 77 pp., 4 pls.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. H. Haskins. 1911. 58 pp., 1 pl.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp.

BULLETIN 9. Recent development of the producer-gas plant in the United States, by R. H. Fernald. 1909. 82 pp., 2 pls. Reprint of United States Geological Survey Bulletin 416.

BULLETIN 11. The purchase of coal by the Government under specifications, by G. S. Pope. 1911. 80 pp. Reprint of United States Geological Survey Bulletin 428.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. 393 pp., 12 pls.

BULLETIN 14. Briquetting tests of lignite at Pittsburgh, Pa., 1908–9; with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 64 pp., 11 pls.

BULLETIN 16. The uses and value of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl.

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs; with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp.

BULLETIN 21. The significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 62 pp. Reprint of United States Geological Survey Bulletin 367.

BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp. Reprint of United States Geological Survey Bulletin 343.

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Bulletin 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 45 pp., 3 pls. Reprint of United States Geological Survey Bulletin 366.

Bulletin 28. Experimental work conducted in the laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 49 pp. Reprint of United States Geological Survey Bulletin 323.

Bulletin 29. The effect of oxygen in coal, by David White. 80 pp., 3 pls. Reprint of United States Geological Survey Bulletin 382.

Bulletin 30. Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907–8, by C. L. Wright. 41 pp., 9 pls. Reprint of United States Geological Survey Bulletin 385.

Bulletin 31. Incidental problems in gas-producer tests, by R. H. Fernald, C. D. Smith, J. K. Clement, and H. A. Grine. 29 pp. Reprint of United States Geological Survey Bulletin 393.

Bulletin 32. Commercial deductions from comparisons of gasoline and alcohol tests on internal-combustion engines, by R. M. Strong. 38 pp. Reprint of United States Geological Survey Bulletin 392.

Bulletin 33. Comparative tests of run-of-mine and briquetted coal on the torpedo boat *Biddle*, by W. T. Ray and Henry Kreisinger. 49 pp. Reprint of United States Geological Survey Bulletin 403.

Bulletin 34. Tests of run-of-mine and briquetted coal in a locomotive boiler, by W. T. Ray and Henry Kreisinger. 32 pp. Reprint of United States Geological Survey Bulletin 412.

Bulletin 35. The utilization of fuel in locomotive practice, by W. F. M. Goss. 28 pp. Reprint of United States Geological Survey Bulletin 402.

Bulletin 37. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. M. F. Goss. 57 pp., 4 pls. Reprint of United States Geological Survey Bulletin 363.

Technical Paper 1. The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp.

Technical Paper 2. The escape of gas from coal, by H. C. Porter and F. K. Ovitz. 1911. 14 pp.

Technical Paper 3. Specifications for the purchase of fuel oil by the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

Technical Paper 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1912. 21 pp.

Technical Paper 9. Status of the gas producer and of the internal-combustion engine in the utilization of fuels, by R. H. Fernald. 1912. 42 pp.

Technical Paper 10. Liquefied products from natural gas, their properties and uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

Technical Paper 16. Deterioration and spontaneous combustion of coal in storage, by H. C. Porter and F. K. Ovitz. 1912. 13 pp.

PUBLICATIONS OBTAINABLE FROM THE SUPERINTENDENT OF DOCUMENTS.

The following technologic publications of the United States Geological Survey can be obtained by sending the price, in cash, to the Superintendent of Documents, Government Printing Office, Washington, D. C.:

Professional Paper 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. $1.50.

Bulletin 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

Bulletin 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

Bulletin 325. A study of four hundred steaming tests made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp. 20 cents.

Bulletin 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes, in charge. 1908. 299 pp. 25 cents.

Bulletin 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 10 cents.

Bulletin 362. Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

Bulletin 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls. 10 cents.

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